Safe Termination of DP Operations using Battery Hybrid DP Systems

Petroleum Safety Authority

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1 EXECUTIVE SUMMARY

The purpose of this report is to contribute to the offshore oil & gas industry's work related to the introduction and operation of vessels/units employing battery hybrid Dynamic Positioning (DP) systems. Battery hybrid DP systems have the potential to provide significant reductions in emissions to air (e.g. CO_2 and NO_x) and operating costs due to their ability to reduce fuel consumption.

This report looks into safety issues associated with termination of DP operations due to the occurrence DP incidents (e.g. technical failure or other hazardous event). The figure below was presented by the (Norwegian) Petroleum Safety Authority (PSA) in 2019 /2/ and shows the number of DP incidents occurring each year in the Norwegian petroleum industry in the period 2014 to 2018. In the context of these incidents, and given the fact that DP incidents may in certain circumstances lead to major accidents, it is easy to see the need for oil & gas operators and other responsible parties to ensure that safe, robust and reliable means of performing termination are in place.

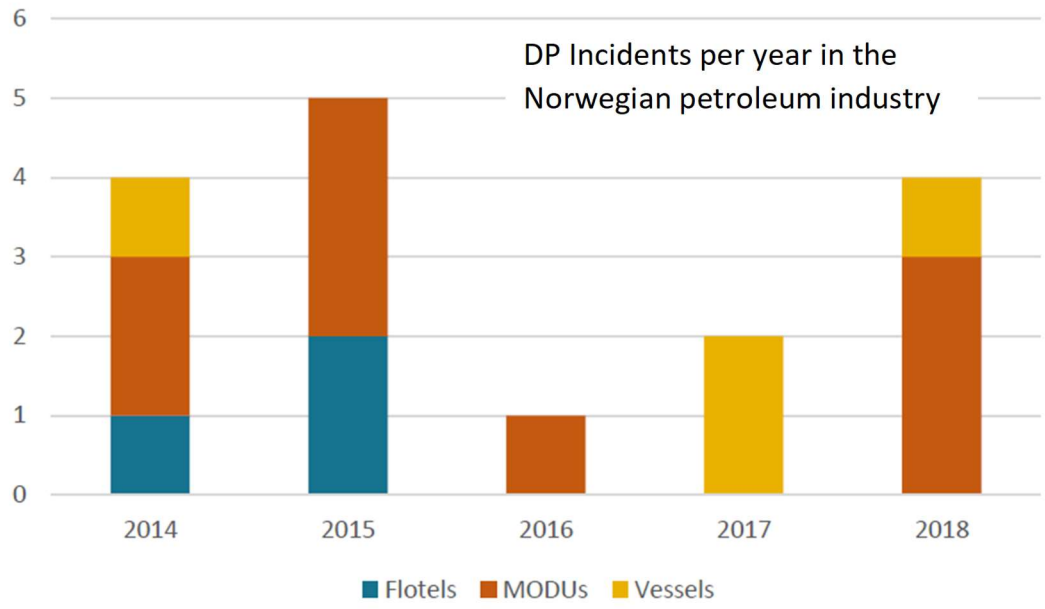

Figure 1 DP Incidents per Year (Norwegian Petroleum Industry, 2014 – 2018)

This report identifies potential challenges to safe termination that can result from the use of battery hybrid DP systems. It is suggested that oil & gas operators and other responsible parties make themselves aware of these challenges and address them where applicable.

This report also provides information on the development of (design) rules related to safe termination and how the time required to safely terminate can be estimated for DP operations. It is hoped that this information is found useful.

2 INTRODUCTION

2.1 General

This report has been produced by DNV GL for the (Norwegian) Petroleum Safety Authority (PSA) (www.ptil.no). The work was performed in the period September to November 2019 and is based primarily on review of documents and knowledge gathered through dialogue with various industry stakeholders (e.g. oil companies, ship/rig owners and equipment suppliers). DNV GL appreciate the fact that stakeholders took the time to contribute to this work.

2.2 Target Audience

This report is aimed at a wide variety of stakeholders from the maritime and oil & gas sectors (incl. both management and technical/operational personnel). Effort has been taken to explain technical and operational aspects in relatively simple terms in order to make information available to stakeholders with limited prior knowledge of Dynamic Positioning (DP) systems and operations.

2.3 Purpose

The purpose of this report is to contribute to the industry's work related to the introduction and operation of battery hybrid DP vessels/units. To these ends the report focuses on the concept of "time required to safely terminate" DP operations, with particular attention being given to the specific challenges raised by the use of battery hybrid DP systems.

2.4 Scope

The report covers the following main topics:

- Introduction to DP systems
    - General
    - Redundant systems
    - Battery hybrid systems
- Introduction to safety in offshore operations using DP vessels
    - Hazards and accident scenarios
    - Barrier strategies and barrier functions (managing risk)
- The concept of time to safely terminate:
    - Regulatory background and current status
    - Implementation in vessel design
- Establishing time to safely terminate
    - Description of general methodology
- Conclusions (incl. summary of challenges)

3 DYNAMIC POSITIONING SYSTEMS

3.1 Introduction

This section provides a simplified description of Dynamic Position (DP) systems. The purpose is to provide non-expert readers with a basic understanding.

3.2 Basics

Vessels are manoeuvred by the use of thrusters. Thrusters are found in a variety of different forms, but can basically be considered as being propellers that provide thrust (i.e. force). Some thrusters act in a fixed direction, while others can be rotated so as to alter the direction in which they act.

A DP system automatically holds a vessel within specified position limits (incl. specified heading limits) by the use of thrusters alone. To these ends thruster force is used to counteract environmental forces, such as those due to wind, current and waves, that if not counteracted would cause the vessel to move (out of position). DP systems are used on variety of vessels that perform many different types of operation. A DP system is typically considered as comprising the following main technical systems:

- Power system – system supplying thrusters with power. Generators are the usual source of power, but batteries are also being used on some vessels. Power is usually distributed by an electrical distribution system controlled by a Power Management System (PMS)
- Thruster system – system providing thrust. Thrusters with integrated electric motors supplied from the electrical distribution system are the usual source of thrust
- Control system – system providing the Human Machine Interface (HMI) as well as directing and monitoring thrusters, so as to keep the vessel in the position demanded by the human operator (i.e. the DP Operator or DPO as they are usually referred to)

The main systems above will be dependent on ancillaries such as fuel oil system, ventilation/cooling systems and such like.

The ability of a DP system to automatically hold a vessel within specified position limits (incl. specified heading limits) is termed *station keeping capability*. A given DP system is designed to provide a given station keeping capability. The station keeping capability is specified by the designer/yard/owner in the design phase and maintained by the vessel operator/owner in the operational phase. Before a vessel can be utilised for a given DP operation it must be verified that it has sufficient station keeping capability for the operation in question.

3.3 Redundant Systems

This section provides an overview of redundant Dynamic Positioning (DP) systems. Redundant systems are those most widely used in safety critical applications in the offshore industry. DP

systems incorporating redundancy typically have the following properties in addition to those general properties described previously in Section 3.2:

- They are designed to maintain required station keeping capability after the occurrence of certain failures
- They can be split into two main categories: DP equipment class 2 (i.e. DP-2) and DP equipment class 3 (i.e. DP-3). These are distinguished by the failure conditions for which station keeping ability must be maintained
- DP-3 is required to be more failure tolerant (i.e. station keeping must be maintained in a wider variety of failure conditions) than DP-2. The differences between DP-2 and DP-3 are summarised as follows:

	Failure conditions for which the station keeping capability must be maintained				
	None - intact DP system	Any active component	Selected passive components	Any passive component	Fire & flooding
DP-2	Yes	Yes	Yes	No	No
DP-3	Yes	Yes	Yes	Yes	Yes

- Post failure station keeping capability is simulated in a system called a consequence analyser. This is an online system installed on the bridge and often integrated into the DP control system. The consequence analyser provides an alarm if the DP system is no longer capable of sustaining a single failure associated with the applicable DP equipment class without loss of station keeping capability. For example, increasing environmental forces (e.g. wind forces) can lead to an increased requirement for thrust in order to keep station. If the required thrust force becomes so high that the DP system will no longer be able to provide it after an applicable failure, the consequence alarm will be activated automatically by the consequence analyser
- The consequence alarm alerts the DP operator to the fact that the DP system is no longer capable of providing the required functionality with respect to failure tolerance. The DP operator should then act to mitigate the situation (e.g. terminate the DP operation)

3.4 Battery Hybrid Systems

In traditional designs the power to the thrusters is provided solely by conventional fuel oil driven generators. Development (and take-up) of battery technology, environmental considerations and a desire to reduce fuel consumption, and thereby operating costs, have resulted in the introduction of batteries as a source of power for DP thrusters. Battery hybrid DP systems utilise a combination of batteries and generators to provide power to thrusters. The inclusion of

batteries facilities better utilisation of generators, which is what provides the benefits described previously.

Some battery hybrid solutions utilise batteries to provide redundancy (e.g. the battery is necessary for the provision of post failure station keeping capabilities). In these cases the post failure position keeping capability can be time-limited due to the limited amount of energy stored in the batteries. Given this the consequence analysis must include a time criterion which represents the minimum time for which the specified station keeping capability must be maintained after failure. To these ends the consequence analysis must monitor the energy stored in the batteries and provide an alarm when there is insufficient energy to provide station keeping for the defined minimum time.

4 SAFETY IN OFFSHORE OPERATIONS UTILISING DP VESSELS

4.1 Introduction

Vessels employing DP systems for station keeping are used to perform a wide variety of activities in the offshore oil and gas industry. Accidents that can occur if the vessel does not keep station (i.e. hold position) as intended include:

- Surface collision with nearby installation, vessel or such like
- Subsea collision with nearby subsea systems, anchor lines or such like
- Disturbance to activity being performed on or from the vessel. Such disturbances can cause a danger to personnel (e.g. emergency disconnect of walk-to-work vessel gangway/bridge), economic loss or pollution (e.g. unplanned release of fluids from drilling riser)

This section contains a simple barrier strategy that illustrates how barrier functions are often used to reduce the major accident risk posed by DP system failure. A more thorough description of the principles of barrier management can be found in PSA's barrier note /1/. Requirements pertaining to barrier management in petroleum activities are described in §5 Management Regulations.

4.2 Generic Barrier Strategy

Figure 2, below, is taken from PSA's barrier note /1/ and provides a schematic representation of how an initial failure, hazard or such like can develop into an accident and which general types of barrier are present to manage the risk.

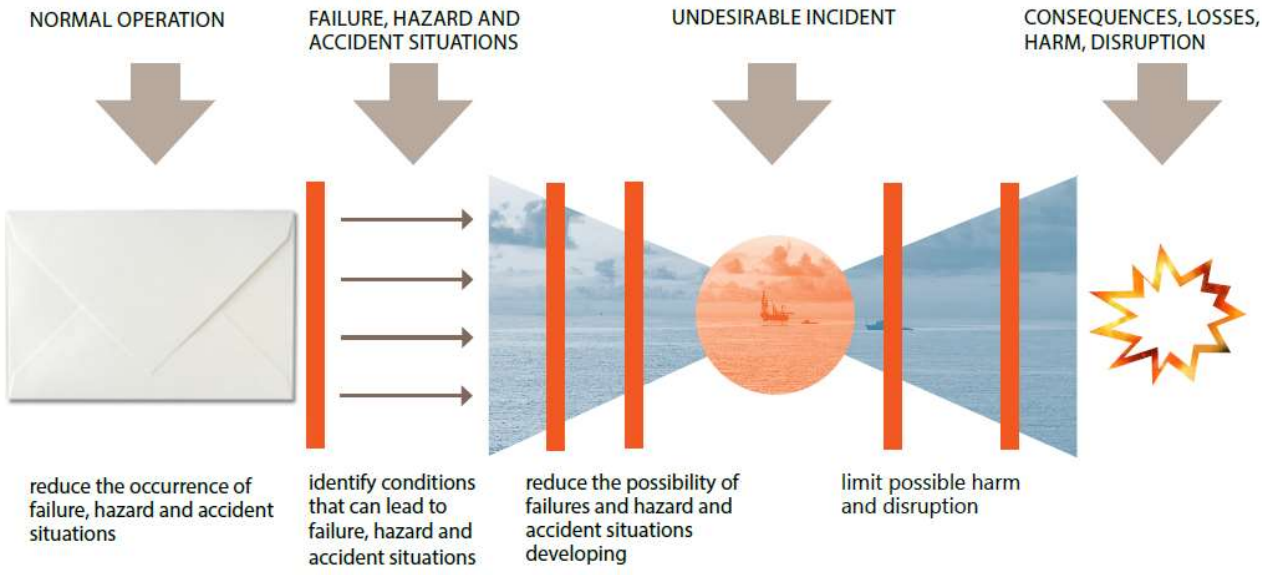

Figure 2 Barrier diagram showing how barriers, in red, are used in to reduce risk

The first vertical red line (i.e. furthest to the left) represents the barrier functions intended to detect deviations outside of *normal operation* (e.g. failures) that have the potential to develop into an accident causing harm. These barrier functions are notable insofar as some of the barrier functions to right, intended to *prevent* occurrence or *reduce* consequences, will be dependent upon successful detection for their activation.

4.3 Barrier Strategy for DP Operations

Figure 3, below, is similar to Figure 2 but is distinguished by the addition of DP specific aspects. The purpose of the figure is to describe a representative barrier strategy that illustrates, in general terms, how barriers are often used to manage risk in DP operations. To these ends the figure shows accident development thorough the following transitions:

- Deviation from normal DP operations (e.g. technical failure or operator error) resulting in a problem posing loss of position hazard; developing into
- loss of position; developing into
- accident causing serious harm

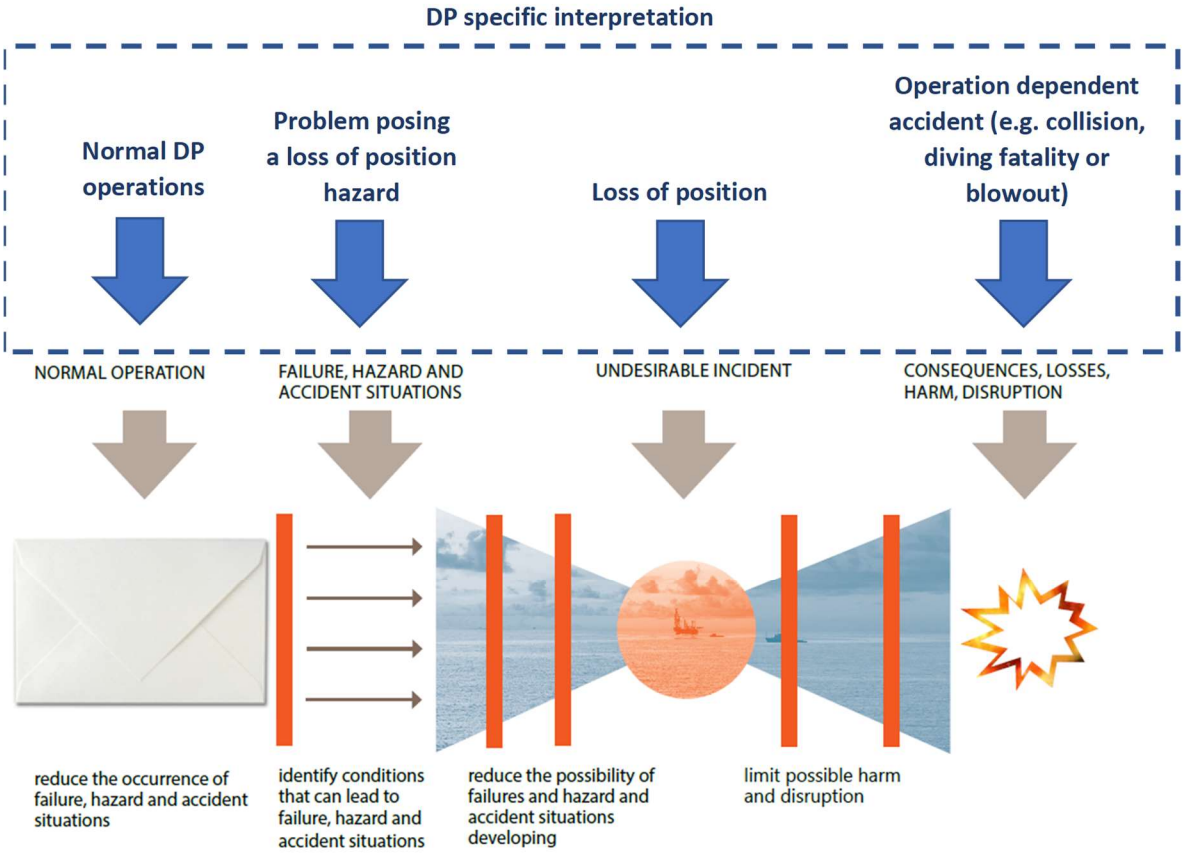

Figure 3 Barrier diagram show how barriers, in red, are used to reduce major accident risk associated with DP system failures

A more detailed picture is provided below in Figure 4. This figure is a simplification (of the real world) and as such does not account for all details, but is nevertheless intended to provide an insight into how barrier functions are often used to manage the risk posed by DP operations. The figure should be read from left to right and is structured such:

- The green symbols represent different aspects of normal (safe) operation
- The orange circles represent hazardous events that can occur and that can cause an accident through loss of position (of the vessel)
- Solid grey rectangles represent barrier functions intended to manage the risk associated with the hazardous event
- Blue lines show accident development (from a hazardous event) and which barrier functions are relevant

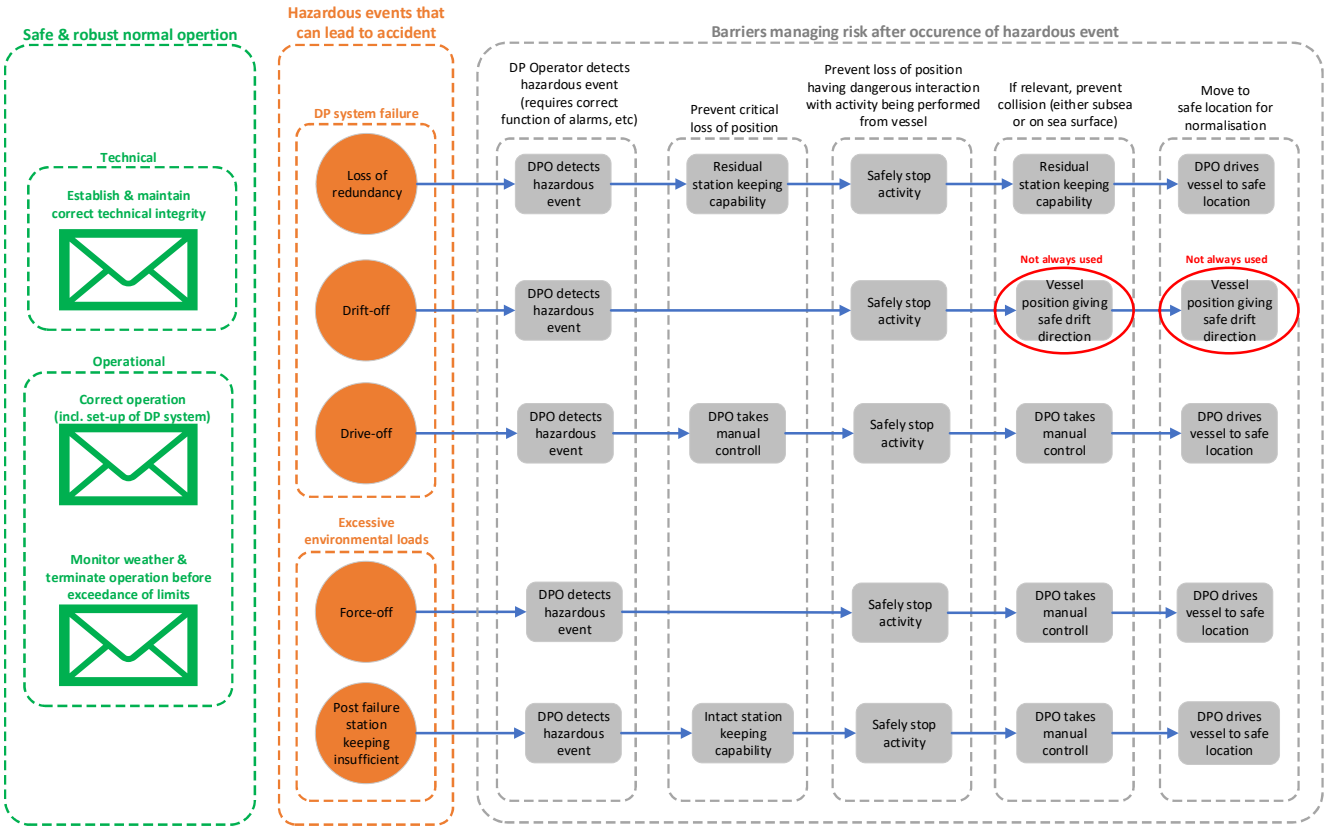

Figure 4 Overview over barrier functions generally applicable to DP Failure

Barrier functions are presented without regard for their actual effectiveness in managing risk. For example, in some situations it may be extremely difficult to "safely stop activity" such that this barrier function will provide for limited risk reduction in the situations in question. The actual effectiveness of barrier functions needs to be considered for each specific situation.

Hazardous events that can cause an accident through loss of position are split into five different categories. These are defined as described below:

- *Loss of redundancy* – Failure of the DP system such that it is no longer capable of sustaining subsequent failures, as required by the applicable DP equipment class, without loss of required station keeping capability
- *Drift-off* – Failure of the DP system causing *insufficient* thruster force (e.g. loss of position due to thrusters not being able to counteract environmental loads adequately)
- *Drive-off* – Failure of the DP system causing *excessive* thruster force (e.g. loss of position due to thrusters actively driving the vessel out of position)
- *Force-off* – Environmental forces (e.g. wind, wave and current) exceed that which the DP system is capable of counteracting in its intact (i.e. failure free) state and force the vessel out of position
- *Post failure station keeping insufficient* – Environmental forces (e.g. wind, wave and current) are high such that the vessel is not capable of sustaining failure, as required by the applicable DP equipment class, without loss of required station keeping capability

The reason for dividing hazardous events into different categories is that barrier functions may differ between them. Differences may include:

- A given barrier function may not be applicable to all hazard categories (e.g. taking manual control of the vessel may be of limited relevance given drift-off as no or insufficient power is available)
- Even if a given barrier function is applicable to different hazardous event categories, performance requirements (i.e. functional requirements) applicable to the barrier function may be different for the different hazardous event categories (e.g. drive-off will usually require quicker termination of activities being performed from/on the vessel than loss of redundancy)

As mentioned previously, Figure 4 is a simplification. For example, no barrier functions are illustrated to prevent loss of position given drift-off or force-off. This has been done to illustrate key differences between the different hazardous events, event though in reality the DPO may be able to intervene to reduce the loss of position in some cases of drift-off or force-off.

4.4 Effect of Time-Limited Post Failure Station Keeping Capability

Time-limited post failure station keeping capability relates to the situation whereby station keeping capability can only be maintained for a short/limited period of time following a failure of the DP system that causes loss of redundancy. The time limit can be due to limited energy stored in batteries providing redundancy. These issues are described in more detail in Chapter 6. The consequence of time-limited post failure station keeping capability is that relevant barrier functions have to have performance requirements (e.g. functional requirements) that reflect this limitation (e.g. the barrier function has to be completed/performed within a certain number of minutes). This issue is considered in more detail in subsequent chapters.

5 TIME TO SAFEY TERMINATE – REQUIREMENTS

5.1 Introduction

Requirements pertaining to DP systems are defined by the International Maritime Organisation (IMO), flags states, coastal states and classification societies[1]. This section provides an overview of the historic development of requirements related to "time to safe termination of DP operations". To these ends the development of requirements from IMO, the Norwegian Maritime Directorate (NMD) and classification societies are presented and discussed.

5.2 IMO DP Guidelines

5.2.1 IMO MSC/Circ. 645 Guidelines for Vessels with Dynamic Positioning Systems of 6th June 1994

These IMO guidelines are the result of the NMD proposal from 1990. The IMO Maritime Safety Committee approved these IMO guidelines at its sixty-third session (16 to 25 May 1994), and they adopted the same "time to safe termination" principle as proposed by NMD. Part 3.1.4 states:

> *3.1.4 Redundant components and systems should be immediately available and with such capacity that the DP-operation can be continued for such a period that the work in progress can be terminated safely. The transfer to redundant component or system should be automatic as far as possible, and operator intervention should be kept to a minimum. The transfer should be smooth and within acceptable limitations of the operation*

5.2.2 MSC.1/Circ.1580 Guidelines for Vessels and Units with Dynamic Positioning (DP) Systems of 16 June 2017

At its ninety eighth session (7th to 16th June 2017) the IMO Maritime Safety Committee approved a new and updated set of DP guidelines. In the preamble to these it is stated:

> *2 It is recommended that the present Guidelines be applied to vessels and units constructed on or after 9 June 2017. For vessels and units constructed on or after 1 July 1994 but before 9 June 2017, the previous version of the Guidelines (MSC/Circ.645) may continue to be applied, however it is recommended that section 4 of the present Guidelines be applied to all new and existing vessels and units, as appropriate.*

The wording in the new DP guidelines is somewhat changed from the old IMO MCS/Circ. 645, but the "time to safe termination" principle remains basically unchanged:

> *3.1.6 Redundant components and systems should be immediately available without needing manual intervention from the operators and with such capacity that the DP operation can be continued for such a period that the work in progress can be terminated safely. The transfer of control should be smooth and within acceptable limitations of the DP operation(s) for which the vessel is designed.*

[1] Some other sources also exist (e.g. guidelines provided by the International Marine Contractors' Association (IMCA))

5.3 Norwegian Maritime Directorate Requirements

5.3.1 Guidelines and Notes No. 28, dated 20.10.94

This includes two enclosures; A and B. Parts 2.7 of enclosure A, which is identical to the proposal the Norwegian Maritime Directorate (NMD) presented in the IMO 26th January 1990, contains the following text:

> *The redundant components and systems should be immediately available and with such capacity that the DP-operation can be continued for such a period that the work undertaken can be terminated safely. The transfer to redundant component or system shall be automatic as far as possible, and operator intervention should be kept at a necessary minimum.*

Enclosure B is the IMO MSC/Circ. 645 Guidelines for vessels with dynamic positioning systems of 6th June 1994. See Section 5.2.1 below.

5.4 DNV GL Class Rules

5.4.1 DNV 1977 "Tentative[2] Rules for the construction and classification of Dynamic Positioning Systems for Ships and Mobile Offshore Unites."

This rule set is considered as being the first international rules for Dynamic Positioning (DP) systems. The rules did not use the specific term "time to safely terminate" or a similar term referring to time. However, the rules included the following basic requirement in Section 2 D400:

> *401 After occurrence of a failure which renders the DP system non-redundant, it should be possible to change the operational mode and/or control mode such that a second failure will not be critical for the function performed or the safety of the vessel.*
>
> *402 Instructions are to be worked out describing necessary corrective actions.*

This requirement is understood to be such that is must be verified that, after a failure, the vessel should have the capability to terminate operations in a safe manner. Even though time is not specifically mentioned it is clear that, depending on design, time could be a significant parameter in such evaluations.

5.4.2 DNV Rules for Ships, January 2001

In this edition of the rules DNV adapted the rules so that the DNV class notations would cover all requirements in IMO MSC/Circ. 645 Guidelines for vessels with dynamic positioning systems of 6th June 1994. In these rules the principle "safe time to terminate" is reflected in Section 2 B200 (201 with guidance note):

> *201 The DP-system is to be designed with redundancy. A position keeping ability is to be maintained without disruption upon any single failure. Full stop of all thrusters and subsequent start-up of available thrusters, is not considered as an acceptable disruption.*

[2] The term tentative rules is used for new rules where the society reserve the right to change the rules at short notice. Tentative rules are just as valid as any other rules and are sometimes used when the society introduces rules addressing new/novel technology where experience from practical deployment in the industry is limited.

Guidance note:
Component and system redundancy, in technical design and physical arrangement, should in principle be immediately available with the capacity required for the DP-system to safely terminate the work in progress. The consequence analysis required in Sec.3 F200 will give an indication whether the position and heading can be maintained after a single failure. The transfer to components or systems, designed and arranged to provide redundancy, should be automatic and the operator intervention should be kept to a minimum.

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Also, the requirement for the DP control system consequence analysis was updated in order to reflect that for operations which could take a long time to terminate, the possibility for changing weather conditions should be considered.

F 200 Consequence analysis
201 *For AUTR[3] and AUTRO notations, the positioning control systems are to perform an analysis of the ability to maintain position after worst case failures. An alarm is to be initiated, with a maximum delay of 5 minutes, when a failure will cause loss of position in the prevailing weather conditions.*

Guidance note:
This analysis should verify that the thrusters remaining in operation after the worst case failure can generate the same resultant thruster force and moment as required before the failure.
The analysis is to consider the average power and thrust consumption. Brief, dynamic effects should be removed by filtering techniques.
For operations which will take a long time to safely terminate, the consequence analysis should include a function which simulates the thrust and power remaining after the worst case failure, based on manual input of weather trend.
Typically, the worst case failure will be loss of one complete switchboard, one engine room, or a group of thrusters that are subject to a common failure mode.

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[3] DNV GL class notations are described here (taken from DNV GL Rules for ships):

IMO equipment class	*DNV class notations*	*Additional information*
Not applicable	**DPS 0**	
	DYNPOS-AUTS	Additional requirements to achieve higher availability and robustness as compared to **DPS 0** will apply.
IMO equipment class 1	**DPS 1**	
	DYNPOS-AUT	Additional requirements to achieve higher availability and robustness as compared to **DPS 1** will apply.
IMO equipment class 2	**DPS 2**	
	DYNPOS-AUTR	Additional requirements to achieve higher availability and robustness as compared to **DPS 2** will apply.
IMO equipment class 3	**DPS 3**	
	DYNPOS-AUTRO	Additional requirements to achieve higher availability and robustness as compared to **DPS 3** will apply.
The **DYNPOS-** series comprise the **DYNPOS-AUTS**, **DYNPOS-AUT**, **DYNPOS-AUTR** and **DYNPOS-AUTRO** notations. The **DPS-** series comprise the **DPS 0**, **DPS 1**, **DPS 2** and **DPS 3** notations.		

5.4.3 DNVGL-RU-SHIP Pt.6 Ch.3. Sec.1 Edition July 2019

The principles are for all practical terms kept unchanged in the following DNV and DNV GL rule editions. There have been some smaller changes to the wording from edition to edition, and in the latest DNV GL Rules for classification the wording is as follows:

> *4.3.1 For DYNPOS(AUTR), DYNPOS(AUTRO) and DPS(3): The DP system shall be designed with redundancy. A position keeping ability shall be maintained without disruption upon any single failure.*
>
> *Guidance note:*
> *Component and system redundancy, in technical design and physical arrangement, should in principle be immediately available with the capacity required for the DP system to safely terminate the work in progress. The consequence analysis required in [6.13] will give an indication whether the position and heading can be maintained after a single failure.*
>
> *---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---*

and:

> 6*.13.1.1 The DP-control systems shall perform an analysis of the ability to maintain position after worst case failures. An alarm shall be initiated, with a maximum delay of 5 minutes, when a failure will cause loss of position in the prevailing weather conditions. In case the redundancy is based on limited energy sources like e.g. batteries then the duration of the delay should be considered.*
>
> *Guidance note:*
> *This analysis should verify that the thrusters remaining in operation after the worst case failure can generate the same resultant thruster force and moment as required before the failure.*
> *The analysis should consider the average power and thrust consumption. Brief, dynamic effects should be removed by filtering techniques.*
> *For operations which will take a long time to terminate safely, the consequence analysis should include a function which simulates the thrust and power remaining after the worst case failure, based on manual input of weather trend.*
> *Typically, the worst case failure will be loss of one complete switchboard, one engine room, or a group of thrusters that are subject to a common failure mode.*
> *Limitations in available power and/or thrust for the relevant worst case single failure condition(s) should be taken in to consideration by the consequence analysis.*
>
> *---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---*

5.5 Other Class Societies

A study of the current DP rules of American Bureau of Shipping (ABS), Bureau Veritas (BV) and Lloyd`s Register (LR) against current DNV GL rules concludes with the following:

- The ABS rules include a similar "time to safe termination" principle

- The BV rules include a similar "time to safe termination" principle

- Similar wording is not found in the LR rules. (However, the requirements to FMEA state that adequate redundancy shall be demonstrated, and it could be that LR would consider that the "time to safe termination" principle would fall in under the term "adequate redundancy".)

5.6 Conclusion

Classification, authority and IMO rules and guidelines require that sufficient time to be available, post failure, for the safe termination of the activity being performed from the DP vessel. The requirements are consistent both over time and between the different sources.

6 TIME TO SAFETY TERMINATE – VESSEL DESIGN

6.1 Introduction

The introduction of battery hybrid solutions has changed the way in which the requirements documented previously, in Chapter 5, are applied in the design of vessels. With this in mind it is natural to distinguish between the following two cases when discussing vessel design:

- Traditional DP designs which do not include time-limited energy sources as part of their DP redundancy
- DP designs which use batteries as part of their DP redundancy. In this case the consequence analysis will consider the energy in batteries as part of the capacity available for station keeping after failure

6.2 Traditional DP designs

In traditional designs the power to the thrusters is provided by a redundant set of conventional fuel oil driven generator sets. It is nevertheless not uncommon for these designs to lack full redundancy in some auxiliary systems. In such cases the post failure station keeping capability may be time-limited (even if this is not accounted for in the consequence analysis). In such cases the acceptance is typically based on Failure Mode & Effect Analysis (FMEA), other system modelling (e.g. heat rise calculations to simulate loss of ventilation) and/or other activities as found necessary (e.g. full-scale testing/trials). Typical examples of traditional designs where post failure station keeping capability may be time-limited include:

- Battery and UPS distribution systems. In older designs it was sometimes approved that chargers and UPSs was not distributed in accordance with the running engine redundancy. Hence, it could be that some control systems could be depending on battery power after failure and there would be a limited time available depending on the available battery energy to supply the control system. This is not in accordance with most current rules and is therefore not common in modern ships
- Ventilation systems or systems for control of ambient temperature (e.g. cooling systems) in computer control rooms, thruster rooms or such like may not be fully redundant; after failure there might be a limited time available before critical equipment is affected by high temperatures
- Fuel treatment and transfer systems, including steam production for heating of heavy fuel oil; after failure there might be a limited time available due to limited amount of fuel or steam to control the fuel viscosity
- Loss of pneumatic pressure on thruster and propeller seals
- For DP-3 systems a fire may also be considered in this context as it may, after a certain time, escalate through A60 class fire divisions segregating different DP redundancy groups

For the above examples there is normally an hour or more available before post failure station keeping is affected. Based on this the safety margins have in many cases been considered sufficient, and such designs have traditionally been accepted based on the situation being handled by crew (e.g. time-limited capability is noticeable to the crew, typically by alarms, and they will have time to act and ensure safe termination or other suitable actions).

6.3 Battery Hybrid DP Systems

Development (and take-up) of battery technology, environmental considerations and a desire to reduce fuel consumption, and thereby operating costs, have resulted in the introduction of batteries as a source of power for DP thrusters. In order to allow for this development both DNV GL and IMO have rules for implementation of DP systems incorporating batteries as sources of power for thrusters. DNV GL first included such rules in the October 2015 edition of the DNV GL rules for classification of ships. These rules are intended to ensure that the integrity of DP systems using batteries is at least comparable to that of traditional DP systems.

Experience indicates that the biggest gains can be achieved when the design facilitates a minimum of machinery (e.g. generators) to be running during DP operations. Vessels that are able operate with connected power systems (e.g. with closed bus-ties) and battery in parallel with a single generator achieve the greatest reduction in fuel consumption and emissions. With this follows the reliance on stored energy in the battery in order to safely terminate DP operations, as the traditional IMO related DP regulations do not accept that redundancy is based on stand-by generators[4].

When safe operation is dependent on the energy stored in batteries it is important to have good control and monitoring of how much energy is available. To provide for this the DNV GL rules have been updated with technical requirements in order to ensure that this information can be provided both to the DP operator and the automatic DP control system, such that the time element can be implemented in the online DP consequence analysis monitoring. Not all relevant DNV GL requirements can be listed in this report, but by way of an example requirements relating to consequence analysis are listed below:

> *6.13.4 When batteries are considered as a redundant source of power to DP thrusters, the consequence analysis alarm shall also be given when the available energy after failure is insufficient for operation according to a given time limit. This limit may be set by the operator, so that it can be adjusted according to the corresponding minimum time requirement for the operation, as determined in the FMEA, or a more conservative value if chosen. However, it shall not be possible to adjust this time below the lowest accepted minimum level. The calculations shall be based on the prevailing weather conditions and experienced operating pattern, e.g. mean net power consumption for the actual operation. The failure mode(s) causing need for the largest power contribution from the batteries after failure shall be considered.*
>
> *Guidance note 1:*
> *Any uncertainty in the accuracy of available energy should be accounted for by adjusting these alarm levels. In addition it should also be considered at which level of charge the battery should be considered to be empty. It*

[4] For alternative DP rules accepting stand-by start as part of the DP redundancy, based on additional requirements in order to increase the availability, see the DNV GL rules for DP notations DYNPOS(E) and DYNPOS(ER)

should also be considered if the termination process will result in additional energy consumption. In such a case this additional consumption needs be taken in to account as well.

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Guidance note 2:
In case the vessel has more than one accepted minimum time requirement, the operator shall ensure that correct time limits, corresponding to the ongoing operations, are being used.

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Attention should be given to guidance note 1 above. This guidance note means that the amount of energy required to terminate should be considered.

As part of the new rules, based on the increased need for accurate control of the "time to safe termination of DP operations" in some of the new DP designs, DNV GL has also implemented a new term, "minimum time requirement" in the latest rule editions. It is this time that is intended to be used in the DP consequence analysis that is required when batteries are accepted as part of the DP redundancy. The minimum time requirement is defined as follows:

Minimum time requirement: minimum required time duration for which the residual remaining capacity as defined by the worst case failure design intent shall be available

Guidance note: The time requirement will normally be governed by the maximum time necessary to safely terminate the on-going operations after the worst case single failure, given the residual remaining capacity. All relevant operational scenarios which the vessel performs and/or participates in should be considered when determining the time requirements. This time requirement should be fulfilled by the design, and the way the vessel is technically configured (technical system configuration) and operated. In addition to the actual time necessary to terminate the operation, the minimum time requirement includes also the time necessary for detection and alarming by the system, and the time needed for the operator(s) to notice, make the appropriate decision(s), and initiate the termination process.

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Also IMO has, in MSC.1/Circ.1580 Guidelines for vessels and units with dynamic positioning (DP) systems of 16 June 2017, explicitly opened for used of alternative energy storage as part of DP systems:

3.2.7 Alternative energy storage (e.g. batteries and fly-wheels) may be used as sources of power to thrusters as long as all relevant redundancy, independency and separation requirements for the relevant notation are complied with. For equipment classes 2 and 3, the available energy from such sources may be included in the consequence analysis function required in paragraph 3.4.2.4 when reliable energy measurements can be provided for the calculations.

The principle of *time to safe termination of DP operations* in not new in rules and regulations and has existed and been used for many years. However, the nature of battery hybrid DP solutions is such that post single failure time available for (safe) termination will often be less than in traditional DP systems. Due to this it is necessary for those operating the vessel to have good understanding and control of the following:

- Time needed to terminate
- Time available to terminate
- Energy available in batteries (post failure) to facilitate termination
- Energy needed from batteries (post failure) to facilitate termination

7 ESTABLISHING THE TIME REQUIRED TO SAFELY TERMINATE

7.1 Introduction

In the context of this document safe termination of a DP operation is defined as being the controlled stopping of the activity being performed from the vessel and, if applicable, the prevention of collision (e.g. with nearby installation) and the subsequent movement of the vessel to a safe location. Exactly what constitutes safe termination needs to be defined for each specific operation. The sections below provide some general guidance. More details are provided in appendix A.

7.2 Methodology

7.2.1 Introduction

This section describes a methodology for estimating the time required to safely terminate. To these ends Figure 5, below, provides an overview of the suggested methodology. The methodology is based on established Human Factors (HF) analysis techniques.

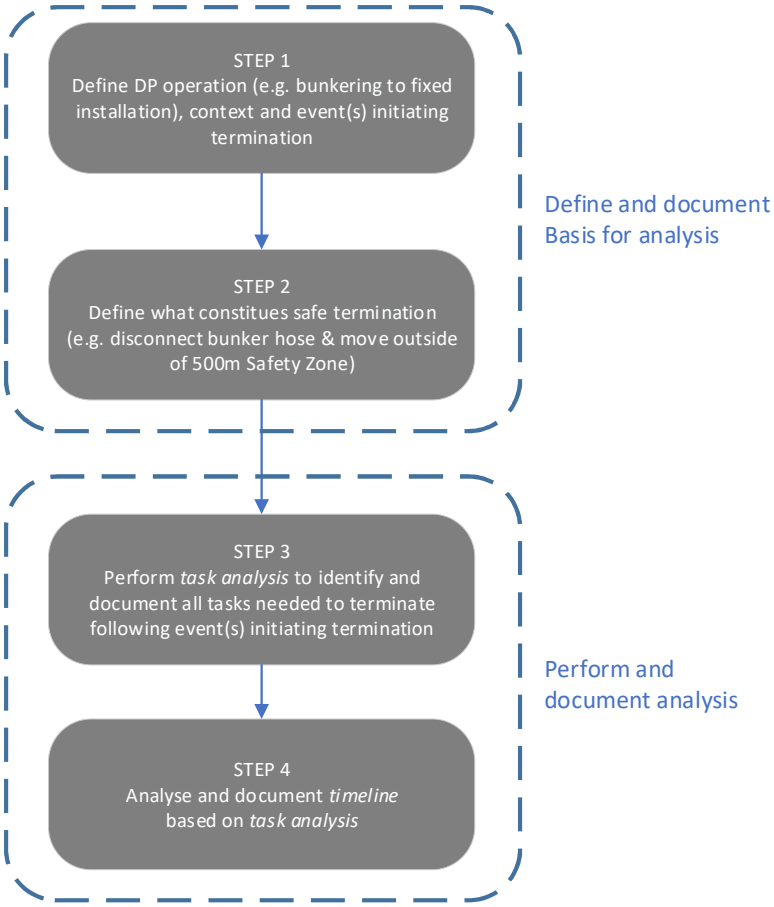

Figure 5 Methodology for Estimating Time to Safely Terminate DP Operation

7.2.2 Steps 1 & 2 – Define & Document Basis for Analysis

The purpose of the first two steps (described above in Figure 5) is to precisely and correctly define the analysis basis. This is important to ensure the validity and correctness of the subsequent analysis.

Events initiating termination, hereafter referred to as *initiating events*, will typically include conditions posing a loss of position hazard (e.g. loss of redundancy, drift-off, drive-off or force-off) as described in Chapter 4. Degrading environmental conditions (e.g. wind, waves or current) can also initiate termination of operations.

It may be the case that different means of termination are appropriate for different initiating events. For example, immediate activation of Emergency Disconnect Sequence (EDS) may be an appropriate means of terminating drilling given a drift-off, but it may not be the most appropriate means of termination given loss of redundancy (i.e. where more time may be available).

7.2.3 Step 3 – Task Analysis

The purpose of the task analysis is to identify the tasks required to terminate the operation in the appropriate (i.e. specified) manner given the occurrence of the initiating event. The task analysis is based on a simple cognitive behavioral model, described in Figure 6 below, that splits the performance of a given task into four constituent elements: detect, diagnose, decide & execute.

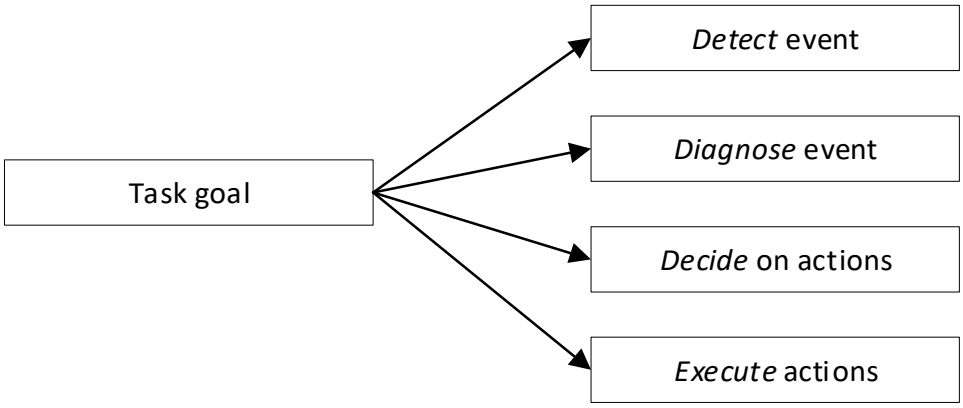

Figure 6 Simple Cognitive Behavioural Model

A generic task analysis for termination of a DP operation is provided in Figure 7 below. The analysis has been produced by applying the simple cognitive behavioural model to the main (generic) tasks tasks involved in terminating a DP operation, which are considered as being:

- DP Operator (DPO) initiating stopping of activity being performed from vessel
- Personnel performing activity stopping the activity
- If applicable, DPO moving vessel to safe location

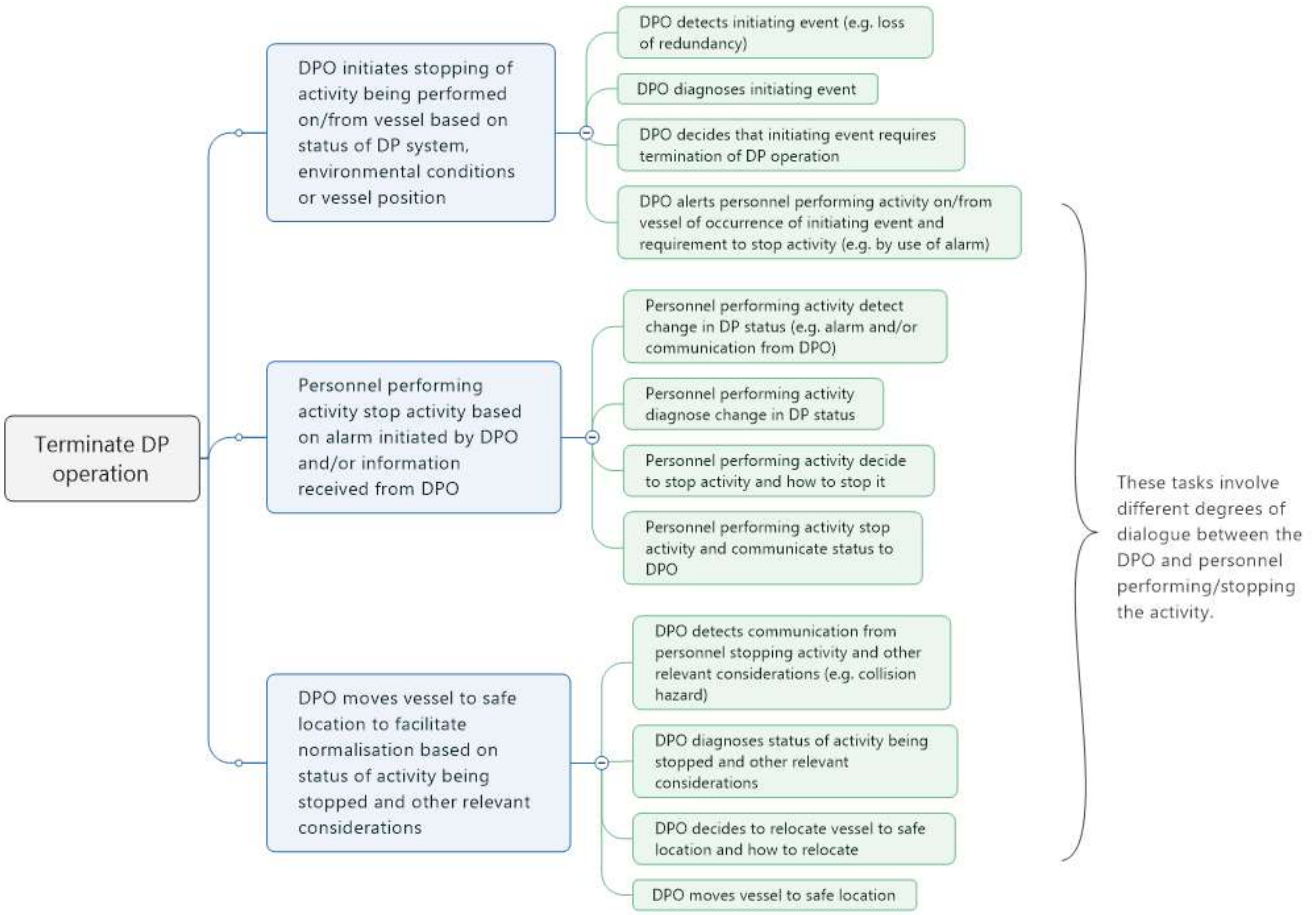

Figure 7 Termination of DP Operation – Generic Task Analysis

7.2.4 Step 4 – Timeline Analysis

The objective of a timeline analysis is to assess the time required to carry out the actions needed to successfully accomplish the defined goal. In the context of terminating DP operations, as considered herein, the timeline should define the time required from occurrence of the initiating event to the successful completion of termination (incl. moving to safe location where applicable). This should include time used by DPO and other personnel as well as any time required for the operation of technical systems.

In essence, calculating the timeline involves taking the elements defined in the task analysis, listing them in chronological order and assigning them a duration. Durations can be assigned based on:

- Information gathered as part of walk and talk through during a site visit or workshop
- Input from operating personnel with experience from actual (or similar) events
- Data from relevant drills or training activities, e.g., emergency preparedness exercises

- Incident reports and investigations in which time has been part of the evaluation

8 CONCLUSIONS

8.1 Challenges

The principle of *time to safe termination of DP operations* has existed and been used for many years. However, the introduction of battery hybrid DP systems represents a significant change in context. Systems using batteries as part of their DP redundancy are such that post single failure time available for (safe) termination can be less than with traditional DP systems. In some situations this can pose a challenge to safe termination and as such particular attention should be given to this issue. To these ends the party operating the vessel should, for each activity/operation, have a thorough understanding of the time required to safely terminate and also the:

- Time available (post failure) to terminate
- Energy available in batteries (post failure) to facilitate termination
- Energy needed from batteries (post failure) to facilitate termination

Time and energy are interlinked. Short termination periods and stable power consumption pose limited challenges, whereas longer termination periods and/or varying power consumption can potentially pose more of a challenge. The party operating the vessel should be particularly vigilant of situations whereby power consumption can increase during termination, for example:

- Due to the nature of termination activities (e.g. operation of power consumers as part of termination activities)
- Due to changes in environmental forces (e.g. due to heading change during termination or sudden change in weather)

The time required to safely terminate an operation is an important safety parameter and as such it is important that maritime personnel and personnel performing activities from the vessel (e.g. project personnel) have a common understanding of it. Clear operational responsibilities should be defined and implemented:

- Personnel with responsibility for operation of the DP system (e.g. DP Operator) must ensure that the time required for safe termination is always available
- Personnel with responsibility for performing activities must ensure that they can always terminate the activity within the required time frame

Good communication between involved parties, both in the planning and operational phases, is important to ensure safety. It is also important that the party operating the vessel have a thorough technical understanding of the battery hybrid DP system, its post failure performance and the operation of the consequence analysis. Some elements of these are rather more complicated that for traditional DP systems and as such special attention may be required to ensure that personnel/organisations have an adequate level of system specific competency and risk awareness.

8.2 Estimating Time Required to Safely Terminate

Time required to safely terminate can be established by using the methodology described in Figure 8 below. The methodology is based on established Human Factors (HF) techniques. It should be noted that it is particularly important to clearly define what constitutes safe termination for each operation under consideration.

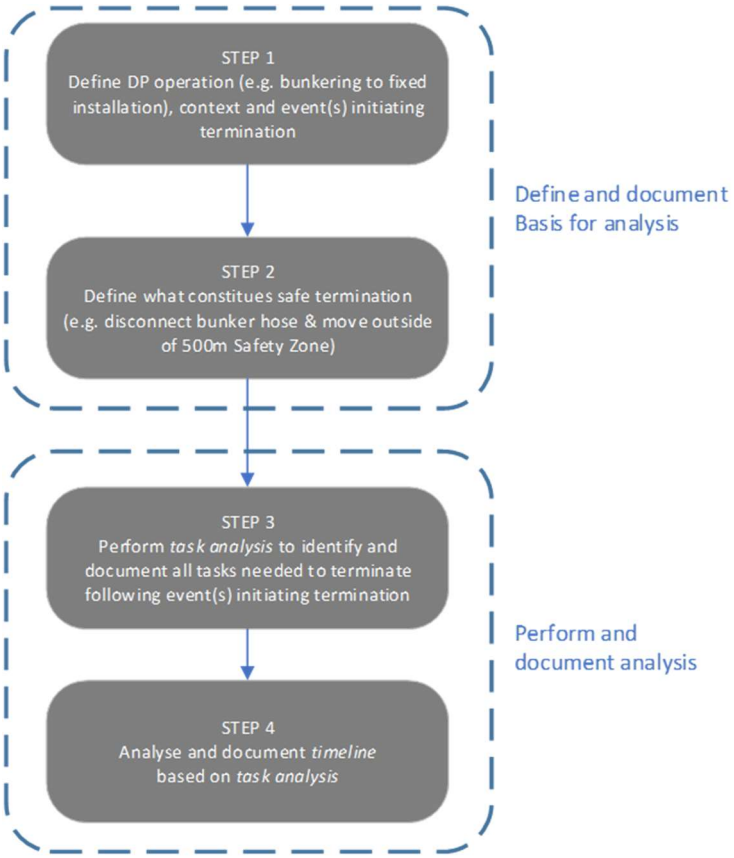

Figure 8 Methodology for Estimating Time to Safely Terminate DP Operation

9 REFERENCES

/1/ *Principles for Barrier Management in the Petroleum Industry*, Petroleum Safety Authority, version 3, 15.03.2017

/2/ Presentation held by Lars Geir Bjørheim at *Konstruksjonsdagene 2019* (seminar), Petroleum Safety Authority, 28th August 2019 (https://www.ptil.no/fagstoff/utforsk-fagstoff/fagartikler/2019/oppsummering-av-konstruksjonsdagen-2019/). Figure originally published by Kvitrud, Arne "Learning from dynamic positioning events." ASME 2019 38th International Conference on Ocean, Offshore and Arctic Engineering. American Society of Mechanical Engineers Digital Collection, 2019.

APPENDIX A
Methodology for Establishing Time to Safely Terminate – Additional Details

Table of contents

1 INTRODUCTION

In order to establish an estimate of time required to terminate a DP operation safely, it is critical to first define the boundaries for the scenario. What is the triggering event and when has the DP operation been terminated safely? Once the boundaries for the scenario have been defined and the contextual (and performance shaping) factors identified, the scenario needs to be broken down into steps or tasks. This can be done utilizing a task analysis. After the scenario has been broken down into steps a time estimate needs to be made for each of these steps, it is also useful to create an overview of relevant, overlapping processes, so that a critical time path can be established. This appendix explains the different steps in more detail and provides examples of how this can be done. These methods are based on established human factors analyses; however, they are a recommendation for determining time required to safely terminate a DP operation and other methods might be also be suitable. The method has been adapted from steps described in the Petro-HRA guideline (Bye et al., 2017) and have been tailored to the meet the needs of the analysis of time to terminate a DP operation safely.

2 SCENARIO DEFINITION

Central to establishing the scenario definition is the *scenario meeting*. This meeting is focused on discussing the scenario(s) that are to be analysed. The meeting should include, as a minimum, a Human Factors (HF) expert and two or three operators from the vessel (including a DPO and project personnel or such like)). It may also be useful to include other personnel such as a supervisors or trainers.

The scenario should be discussed in detail in this meeting; if possible, a high-level talk through of the scenario should be performed to help the analyst understand the key operator activities, and to define key parameters for the scenario. The HF expert should define what is meant by "start" and "safely terminated" for each of the relevant scenarios. The HF expert should also seek to identify relevant documentation (e.g., operating procedures, system description documents, previous analyses, etc.) that will provide useful background information and inform the scenario description.

Some key questions that the HF expert should try to answer in the scenario meeting are listed below:

- What will the time estimate to terminate the operation safely be used for?
- What should be the starting point for the analysis?
- What is considered a safe termination?

Based on the information gathered a scenario description should be developed. The scenario description forms the basis for the subsequent qualitative data collection and task analysis. By creating a specific scenario description, it is possible to determine the boundaries of the time estimate and document the assumptions made. More importantly, the scenario description acts as a communication platform and helps to create and maintain a common understanding of the scenario and its boundaries and assumptions.

There are several ways to describe the scenario, but as a minimum, it should include the following:

- *External environmental conditions* – Location, weather, orientation, time of day, etc
- *Operational mode* – The operational and DP mode of the vessel
- *(Safety) system/barriers* – The function and performance of the various safety systems/barriers involved in the scenario, i.e., what the system "do" and how they do it. The performance requirements for each safety system/barrier can also be documented here (e.g. time the technical system takes to operate). Interaction and dependency between systems should also be investigated and documented here
- *Personnel roles and responsibilities* – The main actors involved in the scenario and their responsibilities, including relevant personnel offshore and onshore
- *Initiating event* – The event that initiates the scenario should be clearly defined. Examples include switchboard failure, increased weather, blackout, console blackout, thruster failure, etc. It is important to detail the type and severity of the event. For example, merely stating "loss of position" is too ambiguous; instead, the description should at least provide the following information:
    - What caused the incident
    - Consequences of the initiating event

- *End of event sequence* – This is the "cut-off" point at which the scenario ends, when the operation has been safely terminated. For most time estimates, this will typically be when the vessel is in the safe zone, at the point when human intervention no longer makes any difference to the scenario outcome

The analyst may have to make assumptions about some of these topics because there is insufficient information available, or because there are too many variables. Assumptions should also be documented with the scenario description for transparency. Once the scenario description has been developed, the analyst should verify this with facility representatives to ensure it is valid and credible (Bye et al., 2017).

3 TASK ANALYSIS

Once a clear scenario description is created, the HF expert should perform an initial task identification using the information from the scenario description. The analyst can use this to organize the information collected and identify knowledge gaps that need to be addressed in the qualitative data collection. A simple Hierarchical Task Analysis (HTA) (Kirwan, 1994) format is useful for performing the initial task identification. The HTA provides a good visual aid for talking through the scenario and discussing the task steps.

The analyst should start by identifying the overall goal of the operator and system task(s) in the analysis scenario, and then identify the task steps that are necessary to achieve that goal. A simple cognitive behavioral model, as shown in Figure 1, may be used to help identify operator tasks.

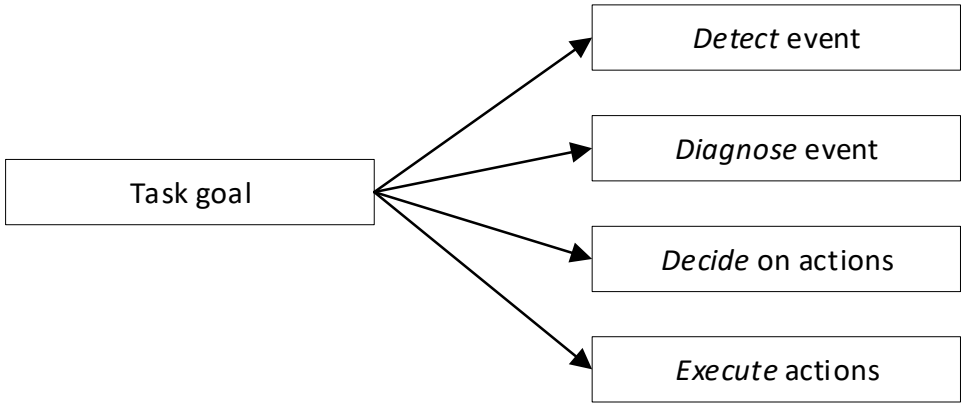

Figure 9. Simple Cognitive Behavioural Model

An example of a general HTA is provided in Figure 2. A HTA, however, contains only a limited amount of information about the tasks. It is therefore recommended that a Tabular Task Analysis (TTA) (Kirwan, 1994) should be developed as this allows for richer information capture and better data organization.

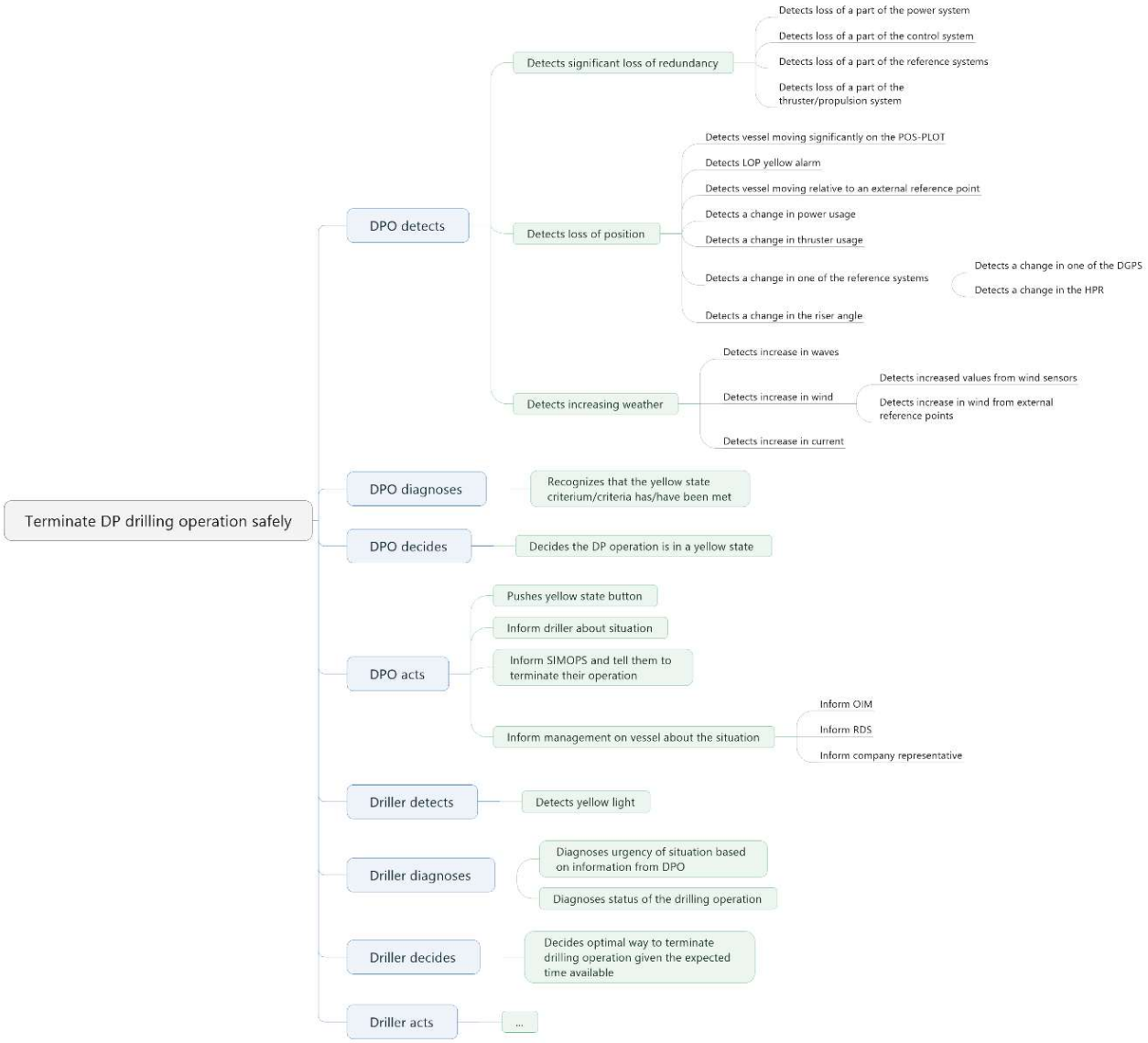

Figure 10. Example of a Partial HTA for Terminating a DP Drilling Operation.

The analyst must decide what data is needed for the TTA, informed by the scenario definition and qualitative data collection steps. To get an overview of the critical time path for the events it is important to document which tasks take place at the same time, or overlap, and which order tasks need to be executed, and other information that might affect the duration or success. An example of what a TTA should include:

- *Task (step) number* – The number of the task step as per the HTA. Using the same numbering system will allow for cross-reference between the two task analyses

- *Task step description* – Description of what the operator does to perform this task step

- *Cue* – Description of the cue for the operator to carry out this task step. For example, this may be an alarm, a step in an operating procedure or instruction, or an indication on an instrument panel

- *Feedback* – Description of the feedback that the operator receives to know that the task step has been correctly performed. For example, a red indicator light changes to green

- *HMI, displays and controls* – List of the displays and/or controls used to perform the task. If there are known issues with these, the issues should be noted in the TTA (e.g. in the notes column)

- *Relevant performance influencing/shaping factors* – Factors that might influence the time needed to execute the task or influence the success of the task

- *Responsible* – Responsible operator, role or system

- *Assumptions* – Any assumptions for the task, the roles involved, etc

- *Notes* – Additional notes

- *Procedure reference* – Document number and procedural step number (if applicable)

4 TIMELINE ANALYSIS (ESTIMATING TIME REQUIRED)

Time is an important factor in DP incidents, with operators having to respond within minutes or even seconds of the initiating event to mitigate the effects of a loss of position or other DP related incident. Therefore, a timeline analysis is required to understand the relationship between operator tasks, the time required to perform the necessary tasks and the time available to the operator to perform these tasks.

The analysis of time required, or time to safely terminate the operation, maps the length of tasks (usually measured in seconds or minutes), and identifies where tasks may be performed in parallel, or where dependencies between tasks exist (e.g., one task cannot be started until a previous task has been completed). These tasks include tasks carried out by (human) operators as well as technical systems. They are also relevant for the critical time path and total time required to terminate the operation safely.

Required time can be directly deduced from various data sources, such as simulators, on-site observations, and incident reports, etc. The data often provides a realistic and accurate estimate. However, it might be challenging and/or costly to obtain. A practical alternative is to estimate required time based on a structured review of the task analysis, i.e. a timeline analysis.

The objective of a timeline analysis is to assess the time required by the operator(s) and system to carry out the tasks needed to successfully accomplish the defined goal. The following input is required for the timeline analysis:

- A complete task analysis
- Information gathered as part of walk-and-talk through during a site visit or workshop
- Input from operating personnel with experience from actual (or similar) events
- Data from relevant drills or training activities
- Incident reports and investigations in which time has been part of the evaluation

According to Bye et al. (2017) the timeline analysis should consist of the following steps (directly quoted from Bye et al., 2017):

- List task steps on the first level in the task analysis (i.e. level 1.0) vertically together with who is responsible for carrying out each task

- Draw a timeline horizontally using a scale suitable for the duration of the task and scenario being analyzed. Time = 0 is defined by the physical initiation of the event (see Figure 3 for an example)

- Include the next point in time, which will be the first cue presented to operators indicating the initiating event. This is typically an alarm, a visual observation of the event, or a physical sensation

- Discuss the duration of each following task step using the details captured in the task analysis:
    - Assess the time required to complete each individual task (i.e., sub-tasks) under each task step illustrated in the timeline diagram
    - Consider the impact of task sequences and frequency by reviewing the task analysis plans – e.g., look for repetitive or simultaneous (parallel) tasks

- Examine whether the availability of equipment and information influences the duration or time required to perform various tasks
- Ask about how long it takes to perform cognitive or interpersonal tasks – e.g. individual or collective problem solving and decision-making
- Include time passed due to expected various disturbances and distractions, such as people entering the control room, phone calls and radio communication, etc
- Ask how the operators are trained to respond to the task (fast or slow)
- Check for shortage of time within the entire task – e.g., are there steps within the task which have limited time available, and what is the consequence of failure?

- Time estimates are recorded in a table containing the following columns:
  - Task step: Name of task step with numerical reference to the task analysis
  - Duration: The estimated duration of each task step being considered
  - Comments: Notes about clarifications, uncertainties or additional information

- Conclude on when the last task required to successfully accomplish the task is taken. The duration from Time = 0 to Time = task completion equals the estimated time required

- For completeness, mark the time when the effect of the task is evident – e.g. when:
  - The rig is disconnected from the lower marine riser package.
  - The hose has been disconnected.
  - The divers are back in the bell.
  - The load has been secured.
  - The ROV has been recovered.
  - The vessel is at the safe zone.

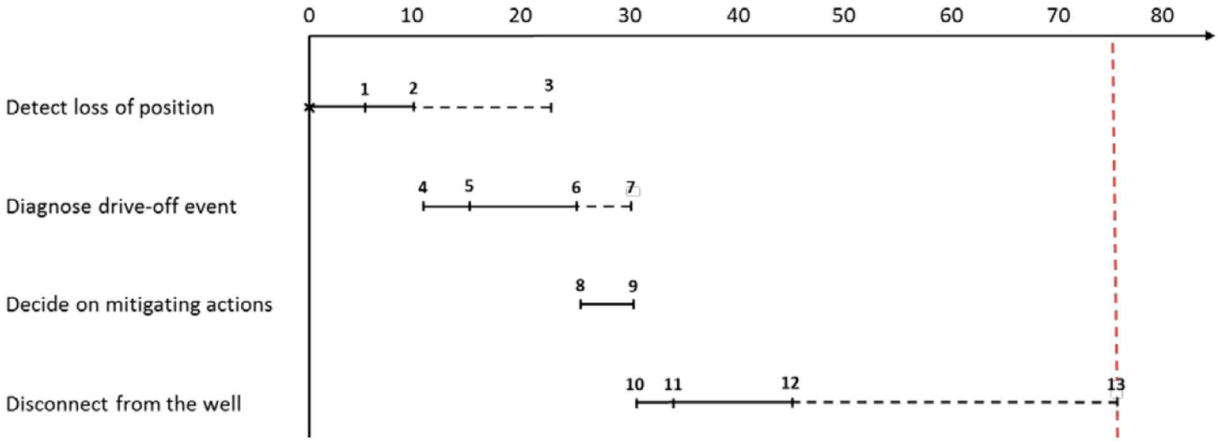

Figure 3. Example of a timeline for safely terminating a DP drilling operation.

Bye et al. (2017) further state that conducting a timeline analysis is tricky and attaining a representative result can be challenging. Therefore, they recommend some additional good practices (directly quoted from Bye et al., 2017):

- *Check for uncertainties* – For some tasks, or parts of tasks, it may be difficult to obtain an accurate and reliable estimate of time required. Data collected via interviews and group discussions may contain uncertainties produced by differing opinions and experiences of the people providing input. The analyst should try to facilitate discussions and interviews in ways such that the level of uncertainty is minimized. Uncertainties must be highlighted together with potential impact on the risk and recommendations about how to reduce the uncertainty. The uncertainty should be recorded with a "conservative" upper and an "optimistic" lower boundary, so the practical outcome of this is an interval for expected time required

- *Avoid input biases* – It is recommended not to reveal the available time to personnel providing input to the timeline analysis, such as operators participating in a workshop. This may make them biased towards this estimate and may influence their perspective on how much time is required. If revealing the available time is inevitable, this bias effect can be mitigated by presenting alternative time estimates for time required from for example incident reports and accident investigations

- *Triangulate perspectives* – The workshop participants' perspectives on time may be significantly different and it is therefore important to triangulate this discussion so that all viewpoints are challenged and considered systematically. One way of doing this is to gather inputs individually first, and then present them as part of a plenary discussion

- *Control unrealistic optimism* – While the input from operators responsible for performing the task is valuable, they also have a tendency to be optimistic about how much time is required to perform the task. This is especially relevant for operators who have not experienced the actual event, but have maybe trained for it, or discussed it as part of desktop exercises. To outbalance such optimism, it can be useful to present data from similar events

- *Consider contextual factors* – Beyond the duration of performing the necessary cognitive and physical tasks, time required must include time passed due to expected various disturbances and distractions, or other performance shaping/influencing factors

- *Reflect average performance* – As far as possible, the time required should be estimated according to what is expected given the circumstances of the accident scenario. It should not (for example) reflect the shortest time possible, as performed by the most experienced and well-trained operator on the facility. Instead, time required should reflect the time it takes an average operator to perform all the necessary tasks in a controlled manner, but without hesitation and unnecessary pauses.

The following pitfalls should be avoided:

- *Inconsistent assessment* – Not being consistent in the manner each task step is assessed may result in an inaccurate estimate of the overall time required

- *Deviation from scenario* – The task analysis reflects how the operator(s) will perform in a specific scenario. Deviating from the scenario's context may therefore invalidate the results from the timeline analysis

5 REFERENCES

1. Bye, A., Laumann, K., Taylor, C., Rasmussen, M., Øie, S., Van de Merwe, K., . . . Gould, K. (2017). The Petro-HRA Guideline, Institute for Energy Technology, January 2017
2. Kirwan, B. (1994). A Guide to Practical Human Reliability Assessment. London: Taylor & Francis

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